GEO spacecraft under threat?

Over the last few years, the possibility of a major 'meteor storm' during the annual Leonids shower (17/18th November) has given rise to some concern regarding spacecraft operations. This was based mainly on the possibility that an outburst might equal the 1966 storm, which produced up to 100,000 visible meteors per hour at its peak (Jenniskens 1995; Brown 1999). Due to the possibility of spacecraft operation anomalies caused by physical damage and impact plasma events during such a storm (see McBride and McDonnell 1999), spacecraft operators have put some effort into impact contingency plans and safe-mode operations.

However, during the 1997-2000 showers, a 1966-like outburst did not materialise, and the resultant reduced risk to spacecraft operations meant that no anomalies (to our knowledge) were encountered. Furthermore, in the 1998 shower, a moderate outburst was unexpectedly encountered a full day before the predicted shower maximum. It is perhaps understandable that spacecraft operators may feel that the Leonids behaviour cannot be reliably modelled, or that it does not pose any significant danger. However, the Leonid meteoroid stream is now better understood (particularly after the 1998 and 1999 showers), due to detailed modelling of the orbital dynamics of the stream particles. Asher (1999) retrospectively modelled the 1998 shower and showed that the early outburst was due to particles ejected from the parent comet (Temple-Tuttle) ejected in the 14th century. Furthermore the 1999 peak was successfully modelled. Additionally, detailed consideration of the

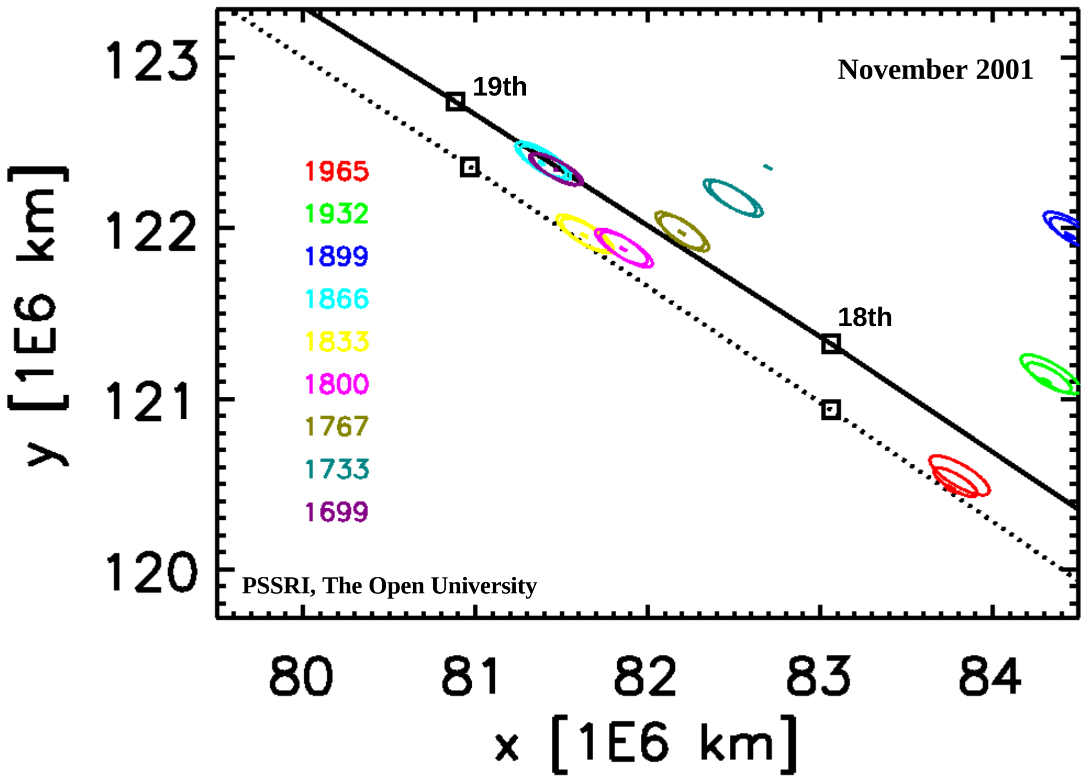

Fig. 1. The intersection with the ecliptic plane, of dust trails produced by meteoroids ejected during various perihelion passages of comet Tempel-Tuttle, are shown for November 2001. The image plane is the ecliptic plane. The solid and dashed lines show the orbit of the Earth and the Moon respectively. The squares mark the positions of the Earth and the Moon at 00:00 UT on November 18th and 19th. The central ellipses (points) are for particles released at perihelion; the outer ellipses correspond to release before and after perihelion.

shower, compared with 1966, showed that a major 1966-like outburst could not have been realistically expected. The forthcoming 2001 shower however, offers an interesting scenario. Brown and Cooke (2001) have shown that a major outburst is considerably more likely than in previous recent years. This is because the stream geometry is rather like the 1966 case.

At the Planetary and Space Sciences Research Institute (The Open University), we have performed detailed orbital dynamics modelling (similar to Asher 1999). We consider the time of ejection from the parent comet (with respect to its perihelion passage), the particle ejection velocity as a function of mass, and the particle ejection direction with respect to the Sun-nucleus orientation. The dynamical integration accounts for the effects of solar radiation pressure on the ejected particles (applicable to sub-millimetre particles) and takes planetary gravitational perturbations into account. A full description is given in Müller et al. (2001).

Fig. 1 shows the ecliptic crossing of the meteoroid 'dust trails' associated with various perihelion passages of comet Tempel-Tuttle, with the orbital paths of the Earth (and Moon) shown. Dust trails produced during the 1767, 1699 and 1866 perihelia pass close to Earth. Note it was the 1866 trail that produced the 1966 outburst, although the trail will now have dispersed slightly. Even so, the shower seen from Earth (relevant to satellites operating in LEO) might well reach in excess of 10,000 meteors per hour at peak.

While being somewhat more 'potent' than in the previous 4 years, of much greater importance to spacecraft operators is the precise geometry of the dust trails with respect to the GEO ring. Fig. 2 shows the geometry of the dust trails associated with the 1767, 1699 and 1866 perihelion passages, with respect to the equatorial plane and the GEO ring. It is seen that 2 of the trails directly cut the GEO ring. The key to a potential hazard, is that the spatial density of meteoroids rises steeply towards the centre of the dust trail. The meteoroid spatial density in this part of the trail could be between 2 and 5 *orders of magnitude* higher than those encountered by Earth. **Clearly, the risk to satellites operating in certain parts of the GEO ring is significantly increased.**

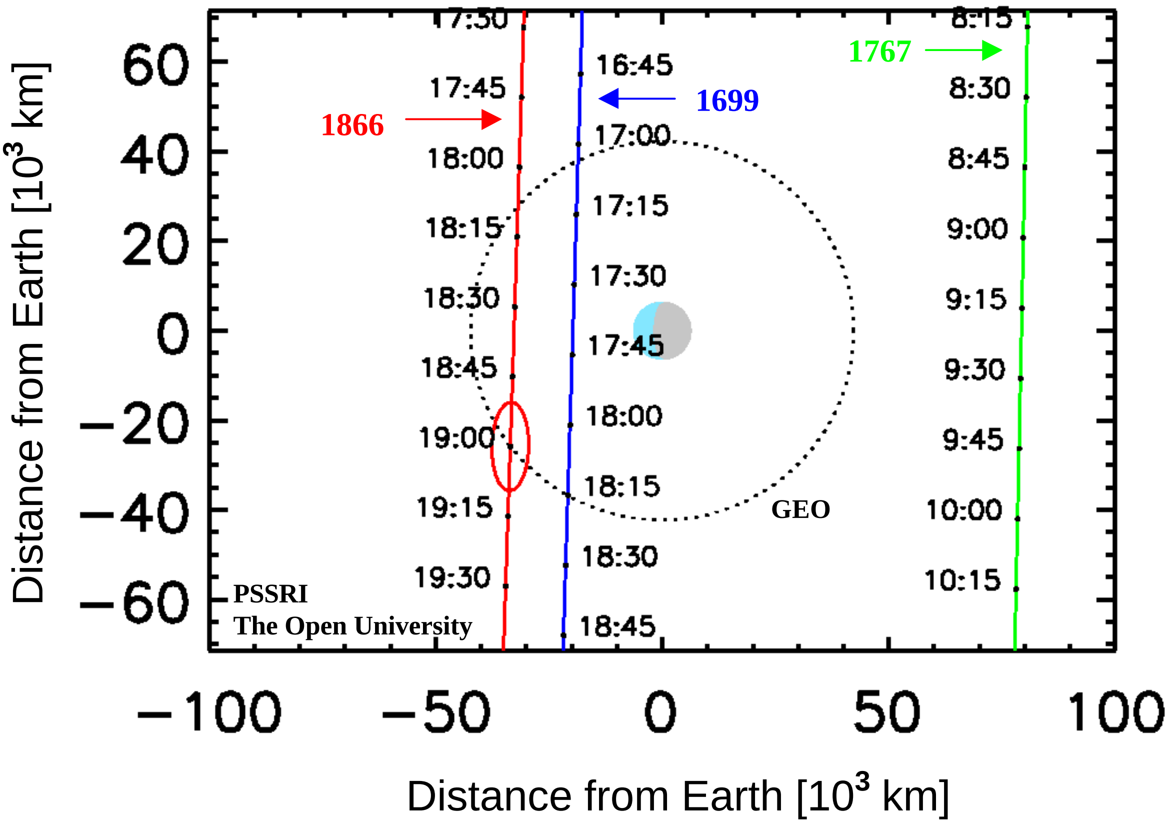

Fig. 2. Intersection points of the three potentially hazardous dust trails with the equatorial plane are shown as a function of time (UT) on November 18th 2001. The Sun direction (projected in the equatorial image plane) is to the left. The ellipse represents the spread of particles released at perihelion (only one is shown for clarity). This ellipse corresponds to the innermost ellipse (points) shown in Fig. 1.

Trail	Crossing	Time (UT 18th Nov 2001)	Longitude
1699	Inbound crossing	17:04 (17:59)	143° W (146° W)
1866	Inbound crossing	18:08 (18:47)	137° W (155° W)
1699	Outbound crossing	18:15 (19:02)	37° W (60° W)
1866	Outbound crossing	19:00 (19:47)	71° W (75° W)

Table 1. The times and longitude when the centres of the 1866 and 1699 large-particle trails cross the GEO ring are given. The values in brackets refer to sub-mm particles (less damaging but more numerous). Note the 1767 trail does not cross the GEO ring; its closest approach to the GEO ring is at around 10:00 UT, at about 150° W. In summary, there is a potential hazard for GEO satellites stationed between longitudes (approximately) 35 and 160 degrees west, between 17:00 and 20:00 hrs UT on 18 November 2001.

Table 1 gives the time (UT) of the GEO ring crossings of the trails, indicating the corresponding operating longitudes for GEO satellites at greatest risk. The values presented here are for relatively large meteoroids (>1 mm diameter) for which the effect of radiation pressure is small. Smaller particles (<1 mm diameter) have also been modelled; a similar situation is seen but the trails can cross the GEO ring up to an hour later.

Although the risk to satellites passing directly through the centre of a dust trail might well be the equivalent of many years exposure to the sporadic background, and the overall impact effects will be greater due to the high impact velocity (about 70 km/s), the possibility of a damaging impact is still relatively low. However, it is clear that the 3 hours on November 18th undoubtedly represents the greatest risk to spacecraft since the beginning of the GEO space-age, and so we felt it was our duty to make this information available to the community.

Summary

The 2001 Leonid meteor shower presents a potential hazard for GEO satellites stationed between longitudes (approximately) 35 and 160 degrees west, between 17:00 and 20:00 hrs UT on 18 November 2001. While overall risk of major damage is still relatively low, this period undoubtedly represents the greatest impact risk to GEO spacecraft since the beginning of the space-age.

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